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ABSTRACT

Public Funding and Corporate Innovation*

We review and condense the body of literature on the economic returns of public R&D on private R&D and find that: (i) private returns to R&D appear to be large and larger than the returns to alternative investments; (ii) private R&D and R&D subsidies are positively correlated and there is no evidence for crowding out; (iii) R&D cooperation increases private R&D; (iv) there appear to exist complementarities between alternative sources of funding; (v) the mobility of R&D workers, particularly of university scientists, is positively related to innovation; (vi) there are many university spin-offs but these are no more successful than non-university spin-offs; (vii) universities constitute important collaboration partners and (viii) clusters enhance collaboration, patents and productivity. Key problems for economic policy advice are that the identification of causal effects is problematic in most studies and that little is known about the optimal design of policy measures.

JEL Classification: C54, J6, I28, O3, L52

Keywords: R&D subsidies, R&D tax credits, cooperation, labor mobility, returns to R&D, university spin-offs, R&D clusters, public-private knowledge transfer

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*The important thing for Government is not to do things
which individuals are doing already, and
to do them a little better or a little worse;
but to do those things
which at present are not done at all.*
–John Maynard Keynes (1926)

1. Introduction

The economic return to public and private research and development (R&D) is of enormous interest to academics and policy makers alike, since public spending in growth-enhancing areas seems more important than ever given austerity and slow economic growth in many countries.

There already exist literature reviews (e.g. Hall and Van Reenen, 2000 on tax incentives; Salter and Martin, 2001 on research-based education). However, we extend previous work on firm-level effects of public R&D policies by synthesizing the state-of-the-art evidence in the various fields of public R&D funding and innovation policies and by integrating these findings into one conceptual framework. Our systematic evaluation and consistent synthesis of the literature enables us to compare the findings in the various areas of public R&D funding throughout countries. We also point out areas for future research

The legitimacy of public engagement in innovation originates from market failure in R&D investments (Arrow, 1962; Griliches, 1979; Griliches, Hall Pakes, 1991; Martin and Scott, 2000; Nelson, 1959; Romer, 1990). Jones and Williams (1998) assess that private R&D investment is just a quarter of the social optimum. Governments hence seek to equate public and private returns to R&D by subsidies and other policy measures.

As shown in Figure 1, our paper reviews the most commonly applied policy measures and knowledge diffusion channels to promote corporate innovative activity: public research and research-based education as a knowledge supplier and supplier of skilled workforce; commercialization of knowledge in terms of technology transfer; R&D collaboration and the public funding of private R&D in form of tax subsidies and direct R&D subsidies.

The literature we review in this survey generates six broad findings: First, private R&D and R&D subsidies (tax deductions or direct subsidies) are positively correlated and

there is no evidence for crowding-out between either types of R&D. Second, R&D co-operation increases private R&D. Third, there appear to exist complementarities between alternative sources of public R&D funding. Fourth, the mobility of R&D workers – and in particular the movement of university scientists to industry – is positively related to corporate innovation. Fifth, there are comparatively many university spin-offs, but these are no more successful than non-university spin-offs. Sixth, research clusters enhance collaboration, patents and productivity.

However, the existing body of empirical evidence is based on surprisingly weak econometric identification strategies. Many studies employ simple before-after estimation and ignore potential (self-) selection effects. This is in sharp contrast to the vast literature on labor market policy measures in which randomized experiments have become the gold standard (List and Rasul, 2011). The lack of solid firm-level empirical evidence is even more surprising since vast amounts of money is poured into these policy measures. In addition, there do not yet exist data sets that allow to study and compare different policy schemes enacted within the same country. Relatedly, most existing studies considers a single policy program only so that complementary effects of alternatives funding schemes are not discussed.

This review unfolds as follows. Section 2 describes our methodological approach. Section 3 presents the findings on public funding of R&D investments. Section 4 deals with the effects of research-based education. Section 5 studies the commercialization of public-private research activities. Section 6 concludes.

*As all economics data files have weaknesses – measurement error, unmeasured variables, sample survey quirks – and all model specifications are questionable, contaminated by data mining, any ‘finding’ ought to be replicated on several data sets and under ‘plausible’ model specifications before one accepts it as valid
–Freeman, 1989*

2. Methodological approach

Our review distinguishes three core areas: (i) public funding of R&D investment; (ii) public research education and the R&D labor market; and (iii) knowledge transfers between public institutions and firms. The conceptual framework in Figure 1 illustrates the interrelations of these elements of public R&D promotion measures.

In order to systemically cover the literature, we formulate research questions for each core area followed by a list of pre-selected high-quality articles. Figure 2 provides an overview of our systematic search.

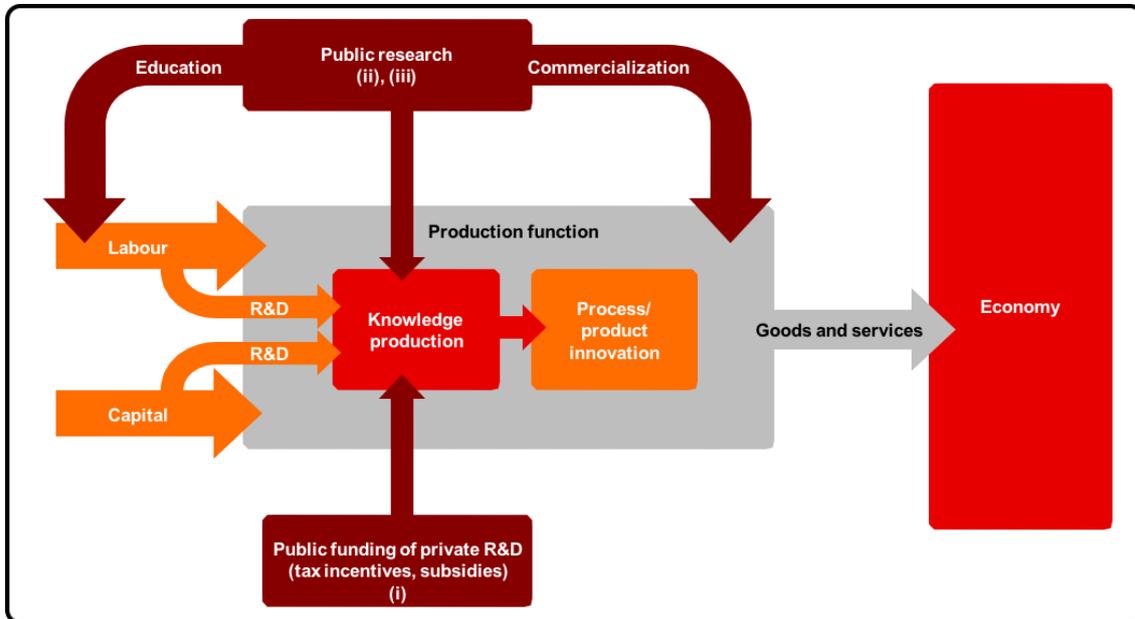


Figure 1 Model of private and public R&D investments

<p>Preselected literature Initially, the authors compiled a list of high quality papers and other writings.</p> <p>Systematic literature search on ECONLIT</p> <ul style="list-style-type: none"> • Five research questions were formulated that covered the review • Two to four concepts were developed for each question • Synonyms for each concept were listed • Search provided us with 2276 journal articles (2010-2016) and 595 working papers (2013-2016) <p>Grey literature 21 homepages of research repositories, government agencies, think tanks etc. were manually searched</p>	<p>Evaluation We screened the literature from ECONLIT in three stages. In the first stage, the initial search output was screened by title, and then in the second stage by abstract. Papers with a very narrow industry focus and with a focus on transitional, emerging, or developing economies were dropped. Finally in the third stage, 204 journal articles and 21 working papers were read and ranked according to methodological rigor, relevance for the review, and importance of findings.</p> <p>We did not score the grey literature. Since it does not have to meet up to certain scientific standards, they are typically much harder to judge.</p>
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Figure 2 Overview of our search strategy

In a next step, we operationalize the search by linking key theoretical concepts and respective synonyms to each research question and use them to search the ECONLIT database. Table 1 shows the core areas of the review, the associated research questions and the derived concepts.

For instance, using research question 1 (“What is the effect of private R&D investment on firm performance or economic growth?”), our approach is as follows:

- Key concepts: R&D, effect, subsidy.

Synonyms: Innovation; impact, return; public, privat; tax, grants, support, programs, collaboration, partnership; spillover; contract research, basic research, applied research, independent research, strategic research; block, funding; competitive funding; investment, additionality, additionalities, crowding, substitution, complementarity.

Research questions and concept area	Research question	Concepts
Effect of public funding of R&D	1. What is the effect of public R&D on private R&D or firm performance?	R&D; effect; subsidy
	2. How does the distribution of public funding/research matter for knowledge, private R&D investment or firm performance?	R&D; public; fund; distribution
Labor market for R&D personnel and education	3. How important is investment in research based education?	Research based; learning; firm
	4. How important is the mobility of R&D personnel for investment in R&D and knowledge diffusion?	R&D; personnel; mobility; diffusion; firm
Knowledge transfer	5. What is the effect of knowledge transfer on firm performance or growth?	Knowledge; technology transfer; effect

Note: Our search was conducted using ECONLIT and resulted in 2276 articles from journals for the period 2010 to 2016 and 595 working papers for the period 2013-2016.

We evaluate the literature from the search output in three steps. First, our screening was based on the title of the paper and second on our reading of abstracts. Columns two and three in the Appendix show the number of papers that went to the next stage. In the third step, we read the articles and gave them points according to relevance (0-5 points), importance of findings (0-5 points) and methodological rigor (0-5 points).

The total number of articles that entered the screening process was 2276. Of those, 592 went into the abstract screening process and were re-distributed to the related research questions. At this stage, we excluded some papers on emerging, transitional or developing economies or papers with a too narrow industry focus and qualitative research that lacked an empirical foundation. Finally, 204 papers met the criteria of our screening process. We defined a minimum threshold score which the papers need to

exceed to enter the review. The final number of papers which we consider in the review is 101.¹

“The prevalence of innovation market failure and underinvestment in technology implies the need to establish a long-term institutional framework for the support of basic research, generic-enabling research, and commercialization”
–Martin and Scott, 2000, p. 445

3. Public funding, private R&D investment and firm performance

The two main public policy instruments available for governments to support private R&D projects are direct public funding (i.e., subsidies) and tax incentives. We first provide a broad overview of the related literature and subsequently discuss heterogeneity of public support with respect to firm size, grant size, types of subsidies and funding sources.

3.1 Overview

Tax credits are considered the more market-oriented response to underinvestment since it leaves the decision of which projects to choose to the private sector. According to Hall and Van Reenen (2000) the associated response elasticities to tax subsidies are, however, so low that it would take a substantial tax amount to generate a socially desirable amount of R&D spending. Reviewing the pre-2000 literature on tax incentives, Hall and Van Reenen (2000) conclude that despite considerable variation, tax credits have a significant positive effect on R&D expenditures that often is larger than the foregone tax income, a result echoed by the review by Becker (2015).

Existing studies on R&D subsidies suggest that the economic benefits from public funding for private R&D are quite substantial. Important reviews in this field include Arvanitis (2013), Becker (2015), David, Hall, and Toole (2000), Dimos and Pugh

¹ We did a similar screening of working papers from ECONLIT where we, however, we applied a stricter relevance criterion since working papers have not yet been reviewed. A list of working papers can be obtained from the authors.

(2016), Klette, Moen, and Griliches (2000) and Zúñiga-Vicente, Alonso-Borrego, Forcadell, and Galán (2014). Increasing governmental support for private R&D has not only given rise to a large and growing number of empirical evaluations but also to a steadily growing interest of policy makers in the evaluation of public support.

Fahrenkrog (2002) as well as Czarnitzki, Huergo, Köhler, Mohnen, Pacher, and Toivanen (2015) provide comprehensive policy reports on public innovation support at the EU level; Jaumotte and Pain (2005) as well as Fosse, Jacobsen and Jacobsen (2014) provide reports for the OECD and Denmark, respectively.

Largely, the more recent empirical literature on direct R&D subsidies rejects crowding out of private funds by public subsidies and points to significant input and output additionality effects. This is in contrast to the earlier literature, which came to the opposite conclusion. Bloom, Griffith, and van Reenen trace this back to clearer policy experiments in more recent years. Another reason for the change in the overall empirical findings may be the application of more accurate econometric approaches suitable to account for non-random selection into subsidy schemes.

In a meta-regression analysis (MRA) on 52 micro-level studies published after 2000, Dimos and Pugh (2016) reject crowding out of private R&D investments by public subsidies. Their findings indicate elasticities of less than .01, meaning that a doubling of the subsidy leads to an increase in private R&D of less than 1%. This figure appears to be low but constitutes the lower bound of the corresponding effect sizes. The MRA also emphasizes the robust and substantial contribution of subsidies to increase private R&D investments. However, with respect to output additionality, the MRA does not show any statistically significant evidence of a substantial output additionality. While this may be disappointing for policy makers, it is more generally a quite typical result for the evaluation of public policies. The authors state, “individual policies can work in the direction intended but yield quantitatively smaller effects than hoped for (p. 810).” In sum, Dimos and Pugh (2016) demonstrate that direct public R&D support does contribute to addressing market failures by increasing both R&D input and output for subsidized firms compared to the counterfactual situation of not having received a public grant. Notably, crowding-out of private R&D investment is clearly rejected, a key finding that is shared by the macroeconomic multi-country study by Bloom, Griffith and van Reenen (2002).

This result can be important if direct public R&D support is used in a broader counter-cyclical policy in order to sustain private R&D investment during economic crisis (Hud

and Hussinger, 2015). In addition, Dimos and Pugh (2016) find that the additionality effects created by the subsidies is increasing over time, possibly reflecting institutional learning. This is also in line with the findings of Klette and Møen (2012), who report that the effectiveness of subsidized R&D has increased over time.

Applying propensity score matching, Czarnitzki and Hussinger (2004), Duguet (2004), González and Pazó (2008) as well as Carboni and Regazzi (2011) reject crowding out for German, Spanish, French and Italian firms, respectively, and find that direct R&D subsidies on average lead to higher private R&D investments. Beck, Lopes-Bento, and Schenker-Wicki (2016) confirm these findings for Swiss firms. They further show that direct R&D subsidies enhance radical innovations, whereas the additionality effects on incremental innovation are insignificant. Their results also indicate that the additional policy-induced R&D investment has similar effects on radical innovation output compared to non-subsidized private R&D.

The rejection of full crowding out is also supported by various studies using other alternative estimation techniques. Aerts and Schmidt (2008) apply difference-in-difference estimation on Flemish and German data. Hussinger (2008) uses two step-selection models on German data while Cerulli and Poti (2012) use matching approaches, selection models and difference-in-difference estimation on Italian data.

In terms of output additionality, empirical studies support that subsidies have a positive impact on innovation performance, as measured, for instance, by patenting (Czarnitzki and Hussinger, 2004; Czarnitzki and Licht, 2006) or novelty sales (Czarnitzki and Lopes-Bento, 2014, for Germany ; Hottenrott and Lopes-Bento, 2014, for Belgium). In a study of Swiss firms, Arvanitis, Donze, and Sydow (2010) find evidence for improved innovation performance of supported firms with respect to six different measures of innovation performance. For Denmark, Bloch and Graversen (2008) report additionality effects of public R&D funding using dynamic panel data regression. They also show that a one percent increase in public funding leads to an increase of private R&D of 0.08-0.11 percent . These findings are in line with an earlier study for Denmark by Kaiser (2006).

One important issue related to the evaluation of tax credit schemes is the so-called “re-labelling problem” (Hall and Van Reenen, 2000). Since a tax credits lower the price of R&D activities, firms have an incentive to declare as many investments as possible as R&D-related s. Hall and Van Reenen (2000) provide econometric evidence for the

effectiveness of fiscal incentives for R&D and conclude that one dollar in tax credits for R&D stimulates one dollar of additional R&D. The more recent literature confirms these findings and points to elasticities larger than one. The estimated elasticities depend, however, on the data, model specifications and estimation method (Arvanitis, 2013; Becker, 2015). Becker (2015) summarizes several prominent studies in this field and concludes that fiscal policy measures, such as tax credits, that reduce the price for private R&D activities increase private R&D investments. Overall, across the different studies, average elasticities are close to unity. Specifically, Harris, Li, and Trainor (2009) report a long-run elasticity of R&D of around -1.4 for manufacturing plants in Northern Ireland, and Lokshin and Mohnen (2012) find elasticities of -0.8 for the Netherlands. Mulkay and Mairesse (2013) report long-run elasticities of -0.4 of the user capital of R&D for a sample of French firms. Berstein and Mamuneas (2005) find elasticities of -0.8 and -0.14 for US and Canadian firms, respectively. The lower elasticities for Canada are also confirmed by Baghana and Mohnen (2009), arguing that the Canadian results are driven by the dominance of foreign firms that are not as susceptible to domestic policy changes. Similarly, Czarnitzki, Hanel, and Rosa (2011) find that R&D tax credits positively affect the decision of whether Canadian firms conduct any R&D at all. Applying propensity score matching, they further conclude that tax credits constitute a suitable tool to induce additional innovation output. For Norway, Cappelen, Raknerud, and Rybalka (2012) report positive effects of tax credits for process innovation and innovations new to the firm. However, tax credits do neither have additional effects on innovations that are new to the market nor on patents.

Castellacci and Lie (2015) show that tax credits are particularly effective in countries with an incremental tax subsidy scheme, such as the US, Japan and France (Castellacci and Lie, 2015). Their multi-regression analysis also shows that R&D tax credits particularly effective for SMEs and firms in the service sector. They conclude that tax credits for R&D activities constitute effective means for firms with low R&D intensities rather than for highly R&D intensive firms in high-tech sectors. This suggests that tax credits designed as an incremental incentive support lagging firms to catch up with the technological frontier rather than to push the technological frontier further

3.2 Heterogeneous effects of subsidies

The recent literature has become interested in finding out where public funding creates most additionalities and how subsidies or tax incentives should be designed. This

section reviews the work on tax incentives, direct subsidies, R&D collaboration and the role of firm-specific heterogeneity for these three policy instruments.

Tax incentives

Warda (2009) provides an overview of different tax schemes applied in OECD countries. Elschner, Ernst, Licht, and Spengel (2011) analyse the impact of various types of tax incentives applied in the European Union on post-tax R&D expenditures of firms in different industries. Their study points out that the most important driver of the efficacy of tax credits is the design of the incentive itself. This refers to questions such as should tax credits be applied on the entire amount of R&D expenditures (volume-based) or on the increase of expenditures (incremental). The study further points out that the tax incentive should be consistent with the general tax system. The study further finds a beneficial impact of immediate cash refunds for unused tax incentives.

Castellacci and Lie (2015) present MRAs of micro-econometric studies on the effects of R&D tax credits on firms' innovation activities accounting for sectoral heterogeneity. Their main finding is that sector affiliation matters. Moreover, the additional effect of R&D tax credits is on average stronger for SMEs, firms in the service sector and firms in low-tech sectors in countries with an incremental scheme.

Finally, Lokshin and Mohnen (2012) investigate the factors that influence the effectiveness of R&D tax incentives. They report that changing the value of the R&D tax parameters does not make a great difference in terms of net welfare gains and that volume-based tax credit schemes are less efficient than incremental tax credit schemes.

Direct subsidies

The study of the empirical literature on the relationship between public R&D subsidies and private R&D investment and innovation performance reveals a considerable heterogeneity of results (Zúñiga-Vicente, Alonso-Borrego, Forcadell, and Galán, 2014). To some extent, this heterogeneity can be explained by methodological issues. However, a more detailed perspective is needed on the distribution of public subsidies. This includes the amount and source of public subsidies (national versus international funding sources), the requirement to collaborate to receive public funding as well as if public funding has different effects if granted to small versus large firms as well as if the composition of corporate R&D (research or development orientation) matters.

The impact of R&D collaboration

The requirement – or at least the encouragement – to collaborate with a firm or a university to receive public support has become an important policy feature of public support schemes. Previous literature shows that R&D collaboration affects the type as well as the success of innovation projects. By means of collaboration, firms can internalize them within the research consortium (D'Aspremont and Jacquemin, 1988). Furthermore, collaboration enables firms to access complementary know-how, capabilities and resources of partnering firms. In sum, the literature emphasizes that R&D collaboration enhances private R&D activities (Cassiman and Veugelers, 2002; D'Aspremont and Jacquemin, 1988; DeBondt, 1997; Kaiser, 2002; Kamien, Muller, and Zang, 1992; Katz, 1986).

With respect to public support for collaborative R&D, subsidized collaborative R&D has received less attention in the empirical literature. Busom and Fernandez-Ribas (2008) show that participation in R&D support schemes generally increases the chance that firms engage in a collaboration with a public research institute or a private firm. Regarding the output additionalities of subsidized collaboration, Sakakibara (2001) as well as Branstetter and Sakakibara (2002) show that participating firms have higher R&D expenditures as well as more patents. Further, applying a matching approach in a treatment effect analysis, Czarnitzki, Huergo, Köhler, Mohnen, Pacher, and Toivanen (2007) find that R&D collaboration has a positive effect on R&D/sales ratios and patent outcomes of public funding for Germany and Finland. Hottenrott and Lopes-Bento (2014) question whether the nationality of the collaboration partner matters. Using a sample of Belgian firms they find that internationally collaborating firm benefit more from R&D subsidies than nationally or non-collaborating firms. Similarly, Beck, Lopez-Bento, and Schenker-Wicki (2016) analyse whether different types of collaboration partners (i.e., horizontal, vertical or collaboration with science) within a subsidy scheme can enhance the effect created by the subsidy. Their study shows that overall collaboration does not affect the sales share of either incremental or radical innovation. However, differentiating between different partner types, their analysis finds that parts of the investment driven by collaboration (horizontal and science) turn negative in the case of incremental innovation. They conclude that the policy effect is not further enhanced by a specific collaboration strategy, and an adjustment of the requirement to collaborate should be considered.

Small- and medium-sized enterprises

Another stream of the empirical literature focuses on the role of firm size. Over the last decades, many innovation agencies have initiated special innovation support schemes for SMEs (Fosse, Jacobsen, and Jacobsen, 2014). The review by Becker (2015) additionally indicates that public subsidies are particularly effective in stimulating R&D of small firms. Usually, small firms are considered as financially more constrained than large firms. In a seminal study, Lach (2002) applies difference-in-difference estimation to a sample of Israeli manufacturing firms. This study reports that R&D subsidies granted to small firms have a significantly larger effect compared to large firms. Another interesting finding is that subsidies may crowd-out private R&D investments for small firms in the short-run, but public support generates strong positive effects after the first year.

The positive effects of subsidies granted to SMEs is also documented by Hottenrott and Lopes-Bento (2014). Applying a treatment effects analysis, their study reveals that public subsidies stimulate additionalities in terms of R&D spending and market novelty sales in internationally collaborating SMEs.

Kaiser and Kuhn (2012) study the long-run effect of a public support scheme for research joint ventures (RJVs) between public research institutions and industry in Denmark. Applying a nearest neighbour matching and conditional difference-in-difference estimation, they find that the insignificant effects for subsidized research consortia in Denmark in terms of value added and productivity are mainly driven by large firms. Considering that large firms are often over-represented in support programs, they suggest rethinking public support policies that are often designed to support large firms.

Another interesting issue from a policy perspective is the question of whether public subsidies can help firms that have previously not been engaged in R&D turn to R&D-active. González and Pazó (2008) show that mainly small and low-tech firms might not have engaged in R&D activities in the absence of subsidies. These findings are also supported Hall, Lotti, and Mairesse (2009) using a sample of Italian SMEs. They find that having received a subsidy stimulates the R&D efforts of SMEs. In a cross-country comparison, Czarnitzki and Lopes-Bento (2012) find that an extension of subsidies to firms that have not received a subsidy would cause those firms to spend significantly more on R&D.

High-tech versus low-tech funding

Policy makers are interested in whether high-tech industries should be particularly promoted. However, consistent empirical evidence on this account is lacking. In this vein, Czarnitzki and Delanote (2015) evaluate the effects of subsidies on input additionalities and output additionalities and compare young high-tech and low-tech firms. They find that additionality effects are particularly pronounced for young high-tech firms. Hence, they conclude that the current focus of EU policy makers on small- and medium-sized, young, independent firms in high-tech sectors seems to be “not ineffective”. This is in line with the findings of Czarnitzki and Thorwarth (2012), who, in a panel data analysis of Belgium firms, find an additional stimulus of basic research for firms in high-tech industries but no premia for low-tech industries.

However, these findings are in contrast to González and Pazó (2008) as well as Becker and Hall (2013) which indicate that firms in high-tech sectors may crowd out incremental public funding for firms’ internal investments.

Size and form of subsidy grants

The reviews by Becker (2015) and Zúñiga-Vicente, Alonso-Borrego, Forcadell and Galán (2014) which also study the effect of grant size confirm an earlier result of Guellec and Van Pottelsberghe De La Potterie (2003) of an inverted U-shaped relationship between the amount of governmental funding and input additionalities as measured in terms of R&D investments. Above a critical threshold of around ten percent, government support crowds out private investments. Those estimates are based on average government funding rates across countries and would ideally be based on grants provided to individual R&D projects instead.

At the firm level, these findings are supported by Görg and Strobl (2007) for Ireland using a non-parametric matching combined with difference-in-differences estimations. Their results indicate that for domestic plants, a grant at the small or medium level does not crowd out private R&D and may even lead to additionalities. Large grants, however, may be used to cover R&D expenses for projects that would have been undertaken even in the absence of the subsidy. All findings suggest the presence of substantial additionality.

Applying a matching approach on German CIS data, Aschhoff (2009) finds that a minimum grant size is necessary to stimulate crowding-in effects for R&D investments

and that subsidy effects depend on project size. She concludes that for a given subsidy amount, larger project sizes correspond to higher chances that the public will support additional crowding-in of private investments. From a policy perspective, taking into account that there are financial constraints for public R&D support, the non-linear relationship between subsidies and the generated additionalities lead to a trade-off between supporting a larger amount of projects at an intermediate level and providing larger amounts of money to few larger projects. Overall, these findings indicate that it is not possible to draw strong conclusions about the relationship between grant size and additionalities.

Funding source

In many countries, firms can apply for grants from different agencies. Those can be national, regional, or supranational agencies such as the EU. The vast majority of empirical studies does not account for differences in the origins of subsidies and estimates an average effect of the subsidies or the effects of a specific subsidy scheme under consideration (Becker, 2015; Zúñiga-Vicente, Alonso-Borrego, Forcadell, and Galán 2014). One of the few exceptions is Czarnitzki and Lopes-Bento (2014) who conduct a treatment effects analysis at the firm level. They analyse the different effects of European and national sources of public funding on R&D investment and patenting. They do not provide evidence for substitutive effects of alternative policies for R&D investment. For patenting, they find positive output additionalities, implying that multiple grants from multiple sources complement each other. Finally, national and European policy measures do not lead to crowding-out effects.

Given the lack of in-depth understanding of how project awarding criteria, requirements and application procedures vary across agencies, and given the heterogeneous empirical results, more research is needed to evaluate the interdependencies of different funding sources. Busom and Fernández-Ribas (2008) go into this direction and analyse the determinants of subsidy program participation using Spanish firm-level data. Their results suggest that firms within an industry face different obstacles in participating in government support programs, causing potential selection problems. Additionally, they argue that program participation patterns depend on the goals of the funding agency and that these patterns differ between high-tech and low-tech industries.

The components of R&D: R vs. D funding

Apart from funding sources, existing studies further distinguish between the individual components of R&D. R&D as a whole does not constitute a homogenous activity, and one should at least treat its major components “Research” and “Development” as separate (Aerts and Schmidt, 2008; Barge-Gil and Lopez, 2015; Clausen, 2009; Czarnitzki, Kraft, and Thorwarth, 2009).

Clausen (2009) distinguishes between public R&D subsidies and analyses their effects on private R&D and innovation outcomes using Norwegian CIS data. He finds that public research subsidies stimulate private R&D investments, while development subsidies are more likely to crowd-out these investments. Hence, public subsidies seem to have stronger stimulation effects for projects where the gap between the social and private rate of return from R&D is larger. From a policy perspective, this paper provides evidence for public support programs to be targeted at novel and uncertain “far from the market” R&D projects. Similarly, Hottenrott, Lopes Bento, and Veugelers (2015) use Belgian data and report positive effects from R&D subsidies on net R&D spending. Specifically, they show that the effect for research grants is larger than for development grants. Interestingly, their analysis reveals the presence of cross-scheme effects that may arise due to complementarity between R&D activities. Notably, their findings on cross-scheme effects of subsidies show that public support can stimulate additional private R&D investment, particularly in research-related activities, and even in the case of subsidies being designed to support development-oriented activities.

Subsidies versus tax incentives

Policy makers can use various policy instruments to stimulate R&D in the private sector. However, there is a lack of understanding of the effectiveness of each different policy instrument. The review by Becker (2015) discusses a few studies that focus on different timing effects between direct subsidies and tax incentives. The bottom line here is that there is a consensus in the empirical literature that tax credits have a significantly positive short-run effect on private R&D investment. By contrast, direct subsidies do not have short-run effects but have positive medium-run impacts

(David, Hall, and Toole 2000; Guellec and Van Pottelsberghe De La Potterie, 2003). An explanation for these findings is that projects qualifying for tax reductions might have been conducted anyway.

There are some countries where direct R&D subsidies and tax credits co-exist. Santamaría, Barge-Gil, and Modrego (2010) analyse the decision making process of a Spanish innovation promotion agency that assigns projects to a set of policy instruments using project-level data. They find that projects that are close to the market are generally well supported through credits, while more basic projects receive more selective support in the form of subsidies. In an analysis of Italian firm-level data, the non-parametric matching approach by Carboni and Regazzi (2011) suggests that tax incentives are more effective than direct subsidies.

Overall, the literature in this field sheds light on potential substitution effects of tax credits and direct subsidy schemes. Hence, a policy mix composed of tax incentives and direct subsidies should be coordinated in an effective way to optimally stimulate additional R&D investment. Little is known about an optimal policy mix, however.

3.3 Wrap-up

Both tax subsidies and direct subsidies stimulate corporate R&D. The existing empirical evidence suggests that tax incentives are effective in the short-run and constitute effective means to increase R&D efforts in SMEs as well as low-tech sectors and countries with incremental incentive schemes. Direct public R&D subsidies require a minimum grant size and a minimum duration to create additionalities. Empirical evidence shows that direct subsidies are especially effective to stimulate innovation in areas with higher degrees of innovation novelty. There are four main policy conclusions: first, any type of policy instrument is more likely to show the desired effects if the policy is integrated into a long-term policy framework and if it is stable over time. The positive effects might be related to the decrease in uncertainty for firms and hence may enable better strategic planning and coordination. Second, there should be internal consistency between the policy instruments used by policy makers. This requires coordination and management between the agencies involved. Third, positive effects from public funding for R&D in the private sector require a minimum amount of governmental support. Fourth, policies instruments and schemes (e.g., awarding criteria, level of grants) should be aligned with national innovation systems and the national as well as the regional industry structure.

"I think it is obvious that the central mission of universities should be the traditional one of the advance and spread of knowledge (...)."
–Richard R. Nelson, 2006

4. Public research, university education and spin-offs

Section 3 has reviewed the literature on the effects of R&D subsidies on innovative in- and output. This section deals with another form of governmental intervention: the direct provision of research and the role of universities in the diffusion of knowledge.

In their reviews of the benefits of public research for industry, Martin, Hicks, and Salter (1996) as well as Salter and Martin (2001) list six main ways through which “research based educations” may impact the corporate world and society at large: (1) the increased stock of “useful” (i.e., commercializable) knowledge, (2) trained graduates, (3) the creation of new scientific tools and methods, (4) the formation of networks and technologically stimulating social interaction, (5) the increased capacity for technological and scientific problem solving and (6) the creation of new firms. Salter and Martin (2001) provide an extant review of the literature on each of these topics.

While we agree that the list by Salter and Martin (2001) is useful, we find some of the items to be hard to distinguish, most importantly items (1), (3) and (5). In addition, there is not much new empirical evidence on items (3) and (5). The next subsections thus discuss the direct effects of public research, namely “useful” knowledge creation and the training of graduates. We treat the creation of new firms in Subsection 5.3.

4.1 Public research and “useful” knowledge creation

Ever since Schumpeter (1934), economists have recognized that R&D is a pronounced driver of growth and that basic, university-based knowledge may play a particularly important role for innovation and productivity (Dasgupta and David, 1994; Dorfman, 1983). The review by Frontier Economics (2014) provides a comprehensive review of the economic growth-related aspects of innovation and R&D, while our review focuses on micro-level evidence.

The early work of Nelson (1959) already discusses important economic aspects of basic research conducted at universities. He mainly deals with the incentives to conduct basic research, and he suggests that research paid by taxpayers should not lead to a temporary monopoly as applied research does when its underlying invention

is granted a patent. He cites case-study evidence for the link between basic science and commercialized innovation to point out that the private sector should have incentives to subsidize public research (and to recognize that the corporate world has incentives to “free ride” from public research efforts). In a late follow-up paper, Nelson (2006) criticizes recent policy efforts to move universities closer to industry, since this may undermine the long-run positive effects of public R&D on industrial innovation. This is a view shared by review articles by Pavitt (1991) and Rosenberg (1990).

Rosenberg (1992) traces the link between university research and the generation of new scientific instruments since World War II, finding evidence for a “causal” relationship that runs from public research to industry. Nelson (1996) uses information on the type of technology that is licensed out at Columbia University to show that instruments and methods are the dominant technologies adopted by private sector firms. Supporting evidence comes from Arundel, Van de Paal, and Soete's (1995) survey data that show that large European firms find “specialized knowledge” to be the most important output by universities.

Survey-based evidence on the usefulness of academic research on industrial innovation is provided by Mansfield (1991, 1995). He uses data on 66 firms in US manufacturing industries (and combines it with information on around 200 academic researchers for his 1995 paper) to show that the surveyed firms indeed report that academic research has been key to their innovative activities. This importance is, however, restricted to only a few sectors: pharmaceuticals, electronics, information processing, chemicals, and petroleum. He also shows a weak link between faculty reputation and university contribution to industry. Regarding geographic proximity of universities, Mansfield (1995) shows that closeness only matters for applied research. Mansfield (1991) also provides estimates for the social return from sciences, which he assesses to be in the range of between 20 and 30 percent.

Arvanitis, Sydow, and Woerter (2008) as well as Beise and Stahl (1999) adopt a methodology similar to Mansfield (1995). Arvanitis, Sydow and Woerter (2008) use Swiss survey data that considers various types of knowledge transfer activities between universities and industry – “general information”, education, research and technical infrastructure and consulting – to show that all significantly contribute a wide range of innovation outcomes. The findings hence support earlier work by Beise and Stahl (1999) for Germany, who study the role of federal research laboratories (like the Max Planck Society or the Fraunhofer Institutes). Beise and Stahl's (1999) survey data

show that their role for commercialized innovation actually is very limited. They also find little evidence for the importance of geographic proximity. Using UK survey data matched with CIS data, Bishop, D'Este, and Neely (2011) show that while a wide range of university-industry technology transfer mechanisms appear to benefit corporate innovation, geographic proximity and university quality do matter for corporate performance. Similar evidence is provided by Howells, Ramlogan, and Cheng (2012), who use UK survey data and to find a positive link between various types of university-industry collaborations.

In a comprehensive study that links around 15000 universities in about 1,500 regions in 78 countries and that goes back to the 11th century, Valero and Van Reenen (2016) find a strong positive impact of the presence of universities on regional growth and firm performance. They identify the supply of skilled workers as a main contributor of both economic growth and innovation performance as measured by patent counts.

Whatever the deeper reasons for the feedback from university to industry are, knowledge spillovers appear to exist. The seminal study by Jaffe (1989) assesses the magnitude of knowledge spillovers using US state-level panel data. He estimates knowledge production functions that consider both spillovers from the private sector and spillovers from universities. His spillover pools are constructed using the technological distance measure introduced by Jaffe (1988). His key finding is that there exists evidence for both public and private spillover effects on corporate patenting and that public spillovers are particularly important in Drugs, Electronics and Nuclear Technology. Jaffe (1989) also provides weak evidence for a causal link that runs from university spillovers to private sector R&D. Using similar empirical approaches and the NBER patent data, Henderson, Jaffe, and Trajtenberg (1998) as well as Jaffe and Trajtenberg (2002) show that university patents receive more citations than corporate patents and that they are more generally applicable. These positive effects of university research occur despite university research being “fundamental” (Rosenberg and Nelson, 1994).

Related work by Zucker, Darby, and Brewer (1994) for US biotechnology finds strong evidence for the importance of university research for private sector R&D. This result that is shared by McMillan, Narin, and Deeds (2000), who use proprietary patent citations data owned by Computer Horizons Inc. (CHI). In more recent work, Belenzon and Schankerman (2013) study the link between geographic proximity and citations to university patents and scientific publications using data on 184 US research

universities. They show that the likelihood of citing a university patent strongly declines with distance and that the likelihood of citing a university patent from an out-of-state university is substantially smaller than the probability of citing an in-state patent. The latter effect is, however, moderated by university quality – it is stronger for lower quality in-state universities. Associated evidence for localized university spillovers comes from Mowery and Ziedonis (2015) using US patent citations data.

Henderson, Jaffe, and Trajtenberg (1998) evaluate how “useful” university research is for private R&D. Their main conclusion is that until the mid-1980s, university patents were more highly cited and cited by more diverse patents than a sample of control group patents taken out by private sector firms. The importance of university patents has, as they show using the NBER patent data, declined since then, despite the “explosion” in the number of university patents. This effect might be traced back to the Bayh-Dole act of 1980 and its expansion in 1984. The decline in the importance of university patents coupled with the increase in university patents might of course simply reflect that the Bayh-Dole act brought about many “unimportant” university innovations, as pointed out by Mowery, Nelson, Sampat, and Ziedonis (2001) as well as Mowery and Sampat (2004).

In work based on the CHI data, Narin and Olivastro (1992) show that the connection between science and industry is by and large only important in pharmaceuticals, chemicals and electronics, thereby echoing Jaffe’s (1988) earlier finding. In a follow-up paper, Narin, Hamilton, and Olivastro (1997) use data on the citations of industrial patents to “non-patent references”, which they argue are likely to be related to university research. They document an upward trend in citations of US patents to these non-patent references which implies an increasing importance of university research for industry. In a study of Flemish firms and their granted patents, Cassiman, Veugelers, and Zuniga (2008) find that patents with non-patent references do receive the same number of forward citations as other patents. However, these patents are more likely to be cited by a foreign patent and to be cited by patents from other technology fields – they hence are more general. While most existing work studies the effects of science on industry, Arora and Cohen (2015) take a reverse perspective by studying the patenting and publication patterns of US corporate scientists over two decades. They show that their contribution to scientific research has decreased but that their contribution to technical knowledge has increased over time.

Meyer (2000) questions this claim by conducting a case study in the nanoscale technology industry. He closely examines the front pages of ten patents to infer how much science these patents actually contain, finding that there is no evidence for a direct relationship between patents that cite university research and university research itself.

Caballero and Jaffe (1993) add a macroeconomic perspective to the discussion by first deriving a neo-Schumpeterian model of economic growth that pins down the link between public research, spillovers, corporate R&D and social welfare. Using the NBER patent data, they show that their empirical results are broadly consistent with their theoretical predictions. An important empirical finding of theirs is that the degree of “usefulness” of public research has steadily declined and that knowledge rapidly diffuses.

European evidence on university-private sector knowledge flows is provided by Bacchiocchi and Montobbio (2010), who use EPO patent application and citations data for France, Germany, Italy, the UK and the US. They first derive a theoretical model similar to Caballero and Jaffe (1993) and estimate it in a semi-structural way. Their results show that university patents are more likely to be cited than corporate patents but that this effect is again primarily driven by chemicals, drugs and mechanics as well as US universities. Maietta (2015) uses data on a low-tech industry, Italian food processing. Even in that low skill, low-tech sector, she finds significantly positive effects of university-industry collaboration on both product and process innovation. Following Narin, Hamilton and Olivstro’s (1997) non-patent citations’ definition of industry-science links, Cassiman, Veugelers, and Zuniga (2008) show that citations to non-patent sources do not lead to more forward citations but that patents with such citations are more widely applicable. Czarnitzki, Hussinger, and Schneider (2011) come to somewhat different conclusions for forward citations of industry patents. Their study is based on a large number of German European Patent Office patents taken out by applicants with a “Professor Dr.” title between 1978 and 2006 and finds that corporate patents that have a science link receive a forward citation premium.

Toole (2007) uses data on the US biotechnology industry to show that public research is positively correlated with private R&D investments but that this correlation occurs with a lag. Following up on his earlier research, Toole (2012) documents an economically and statistically significant positive correlation between scientific publications and the number of new molecules in US biotechnology. Evidence in favor

of complementarity between public and private R&D is provided by Veugelers, Calis, Penning, Verhagen, Bernsen, Bouquet, Benninga, Merkus, Arets, Tibboel, and Evenhuis (2005), who use Belgian CIS data and who account for the potential simultaneity of innovation strategy choices. They also show that large firms and firms in chemicals and pharmaceuticals are most likely to have links to university research.

Somewhat conflicting evidence comes from Quaglione, Muscio, and Vallanti (2015) as well as Muscio, Quaglione, and Vallanti (2013), who use data on the population of Italian university departments to show that there exists some evidence for substitutive effects between public and corporate R&D in life sciences and, less so, for engineering and technology departments. There is, however, evidence for complementarity for departments that focus on basic sciences. Two cross-country panel data studies – Guellec and Van Pottelsberghe (2003) as well as Falk (2006) – try to directly estimate the relation between research conducted at universities and private R&D efforts. Guellec and Van Pottelsberghe (2003) use a panel dataset of 17 OECD countries. They estimate dynamic panel data models and do not find significant effects of research conducted by universities on private sector R&D spending. Falk (2006) reviews existing studies on the link between public and private sector R&D and estimates systems of simultaneous equations using GMM on a panel of OECD countries. He finds that research activities carried out by the public sector lead to an increase in private R&D spending. He estimates a corresponding elasticity of one.

Narin, Hamilton, and Olivastro (1997) link the strong growth of corporate patenting in the period 1987-1994 to the even stronger growth of university, or more generally, public research institution patenting and publishing. They argue that public sector research complements rather than substitutes private sector research, a view shared by Meyer-Krahmer and Schmoch (1998). Klevorick, Levin, Nelson, and Winter (1995) as well as Nelson (1986) explain this phenomenon by basic research generated by universities that expands the technology space of industry, while Mowery (1995) concludes that university research enhances the efficiency of corporate research. Steinmueller (1994) explains the complementarity by basic research reducing the option value of contemporary private research projects. Yet, the broadly accepted explanation for the complementarity of public and private research is absorptive capacity: firms need to invest in R&D in order to be able to understand (to “absorb”) the research conducted by universities (Nightingale, 1997; Pavitt, 1998) and other firms (Cohen and Levinthal, 1989, 1990; Zahra and George, 2002).

Levin, Klevorick, Nelson, Winter, Gilbert, and Griliches (1987) report the key results of the “Yale” survey of US R&D executives. The survey contained questions of the sources of knowledge for innovation. Linking it to R&D intensity and innovation, they show that they are positively related to one another. In follow-up work, Nelson (1986) provides further evidence for a positive correlation between university research and private sector R&D intensity and argues that university research expands technological opportunities rather than generating commercializable innovations itself.

In a follow-up paper, Cohen, Nelson, and Walsh (2002) use Yale survey data to underscore the importance of public research for corporate research. Moreover, they find that public R&D is not only positively linked to the generation of new ideas but that is also positively associated with the completion of R&D projects and that it leads to starting up new research projects. Studying the sources of these effects, they find that the means through which knowledge is transferred from university to industry are academic papers, conferences, informal information exchanges and consulting. They finally show that university knowledge is more important for larger than for smaller firms and startups compared to established firms.

In a sociological study of US and UK corporate scientists, Faulkner and Senker (1994) as well as Faulkner, Senker, and Velho (1995) underscore the importance of personal links between private and public sector scientists. Similarly, Rappa and Debackere (1992) use international survey data on scientists and engineers to show that private sector researchers recognize public sector researchers as an important knowledge repository despite the latter’s tendency to publish inventions rather than to take out patents. Danish evidence on the importance of informal university-industry networks and of geographic proximity is provided by Østergaard (2007) who shows that scientists who had previously been involved in a formal industry-university collaboration or who had studied at the local university were more likely to report that they acquired knowledge from university scientists. The importance of the building of a scientists network is also underscored by Callon (1994) in his review of anthropological and sociological studies. Foray and Lissoni (2010) also survey the older literature on scientists’ personal links between the public and the private sector, finding an overall positive effect.

Using business survey data from large European firms from 16 different industries across European countries – the so-called PACE survey, a predecessor of the Yale survey – Arundel, van de Paal, and Soete (1995) show how the link between public

and private R&D may come about. They demonstrate that the most important source of learning from public research is publications followed by informal contacts as well as hiring, conferences and joint research. In subsequent work, Arundel and Geuna (2004) review the results of their PACE survey, CIS data and the Yale survey and argue that the importance of geographic distance between a potential public research knowledge base increases with the quality of the public research institution. This result is shared by Abramovsky and Simpson (2011), who use British firm-level register data, as well as by Laursen, Reichstein, and Salter (2011), who use British survey data.

Finally, the perhaps second most relevant direct public-private knowledge transfer mechanism after the production of scientists are public-private research collaborations. Cockburn and Henderson (1998) use a sample of ten US pharmaceutical firms to show that research collaborations between public and private sector employees increases the quality of the joint patents as measured by patent citations, which they interpret as a substantial social return to public investments in public research. This key finding is shared by Gittelman and Kogut (2003) for US biotechnology firms. Zucker, Darby, and Torero (2002) underscore the positive effect of university “star scientists” who emphasize that some links to industry are particularly important for corporate innovation in US biotechnology. However, Rothaermel and Hess (2007) show that non-star scientists are of even higher importance.

4.2 University education and the training of graduates

While it is clear that there exist important knowledge flows between university and industry, the most direct transmission channel – the training of future workers – is not well investigated. To study the impact of workers who leave university after a post-graduate stay to join the private sector, Kaiser, Kongsted, Laursen, and Ejsing (2017) combine Danish patent data with assignee (firm-level) data and link these to employee-level data. This enables them to track R&D workers and their employers. They use dynamic count data models that account for the potential endogeneity of firms’ hiring decisions and for firm fixed effects and find that incoming university joiners have a substantial positive effect on their employers patenting activity. More generally, they find any previous exposure to the university research environment to lead to statistically and economically significantly larger effects on corporate patenting compared to joiners from the corporate world without any prior university research experience. This effect is attenuated if the top management team comprises of at least

one member with an R&D background. Kaiser, Kongsted, and Rønne (2015) use the same data set as Kaiser, Kongsted, Laursen, and Ejsing (2017) and show that recent graduates also contribute statistically and economically significantly more to the patenting of their new employer than joiners from non-patenting firms. Recent graduates do, however, contribute less to patenting than joiners from patenting firms.

Other more recent related work includes the papers by Cowan and Zinovyeva (2013), Leten, Landoni, and Van Looy (2014) as well as Rothaermel and Ku (2008). Leten, Landoni, and Van Looy (2014) estimate regional production functions using panel data on Italian provinces and four industries. They find evidence for a positive association between the technological performance of firms and both the number of university graduates and the number of scientific publications within a region. More Italian evidence is provided by Cowan and Zinovyeva (2013) who show that the establishment of new universities and colleges in Italy has led to an increase in regional innovation activity and that this effect is particularly strong for less developed regions. In their study of the US medical device industry, Rothaermel and Ku (2008) identify a “critical role” of universities as a source of regional knowledge spillovers. They also stress the importance of university graduates as a driver of knowledge transfer.

The older empirical literature starts with Gibbons and Johnston (1974), who study 30 UK private sector innovations and find evidence for public research having benefited these innovations. They speculate that the training of students by the public sector might have in particular helped the creation of these innovations. Similarly, Martin and Irvine (1981) conduct a case study in the UK radioastronomy industry to show that innovation in that sector is primarily driven by educated scientists (“manpower effects”) and academic spin-offs. In more narrative work, Nelson (1986) emphasizes the importance of science teaching that endows graduates with the relevant scientific know-how without requiring them to do any academic research themselves. This view is shared by Senker (1995), who emphasizes the importance of a new scientist to absorb new technological knowledge.

Klevatorick, Levin, Nelson and Winter (1995) use the Yale survey to show that one of the main mechanisms through which university knowledge disseminates to industry is the training of industrial scientists and engineers by universities. The other main route is through basic science and its effect on applied industrial research. Junge, Severgnini, and Sørensen (2016) use Danish survey data matched with register data to show that a higher share of tertiary educated workers leads to a higher likelihood of product,

process and marketing innovations. They estimate growth models that account for potential endogeneity of firms' employment choice. Using the Yale survey data, Rosenberg and Nelson (1994) show that the little role that basic science seems to play in the importance for corporate innovation may ignore the long-term effects of basic research on corporate research. The positive long-run effects of science are also emphasized in Adams' (1990) seminal study on the effects of "fundamental" stocks of knowledge that shows that the stock of scientific papers has an economically and statistically significant effect on economic growth and that these effects occur with lags of up to 20 years.

4.3 Wrap-up

There is vast empirical evidence that universities and other public research institutions have a significant economic impact on industrial research, both directly through knowledge transfer and indirectly through the education of scientists. Geographic proximity to universities still appears to play a positive and important role. Proximity does, however, matter most for industry-university linkage of second-tier universities, while there are no such effects for top universities. Digitization may make geographic proximity less important, but social interaction is likely to remain important for knowledge transfer, in particular if industry is not looking for a solution to a specific problem but rather for unspecific inspiration.

This existing evidence is predominantly based on patent citation and survey data. More recently, scholars have begun to use register data coupled with patent and patent citation data as well as surveys. This allow scholars to track the entire working history of individuals. The transfer of public science knowledge to industry is best investigated and documented for a few high technology sectors like pharmaceuticals and electronics. Much less is known, however, about the extent to which knowledge spillovers matter for low-tech industries. In addition, existing research has predominantly studied knowledge flows from university to industry, thereby ignoring possible reverse relationships.

The training of qualified research workers is a second mechanism through which university affects industry. These movements constitute an important mechanism through which academic knowledge disseminates.

A key problem with the existing literature is that causal effects are inherently hard to identify. The sorting and matching of workers is non-random, knowledge flows between university and industry may be bi-directional and characterized by self-selection. Quasi-experiments that have a long tradition in labor economics of the type applied by Christensen, Kuhn, Schneider, and Sørensen (2015) would constitute an important step towards a more proper assessment of university-industry interactions.

*In capitalist economies, technology has two faces –
a private and proprietary one, and a public and cooperative one.
These at once complement each other, and are at odds.
– Richard R. Nelson*

5. The effects of public-private knowledge transfer on firm performance or growth

This section focuses on how knowledge created at universities may stimulate corporate R&D and how it contributes to industrial innovation. In addition to public support mechanisms such as subsidies and tax incentives that we discussed in Section 3, other important policy mechanisms support the commercialization and transfer of technological knowledge from the public sector. We deal with the question of how public support mechanisms and university-industry relationships can enhance the diffusion of knowledge and technology. We focus on academic spin-offs, technology transfer offices, academic consulting and academic entrepreneurship.

Perkmann and Walsh (2007) show that university-industry relationships are very common in the US and that the use of the various links varies across industries and scientific disciplines. They relate the increasing importance of universities for industry to factors such as a growing number of governmental initiatives to promote public-private research partnerships and a steadily increasing political pressure on universities to contribute to national economic competitiveness. Several indicators underline this trend: universities have an increasing propensity to patent (Mowery, Nelson, Sampat, and Ziedonis 2001), generate increasingly higher revenues from licensing (Thursby, Jensen, and Thursby, 2001) and an increasing number of university scholars are active in academic entrepreneurship (Shane, 2004). Furthermore, universities generate a higher share of their income from industry funding (Hall, 2004),

and establish an increasing number of technology transfer offices, industry collaboration support offices and science parks (Siegel, Veugelers, and Wright, 2007).

By establishing university-industry linkages, universities take an open innovation perspective. Perkmann and Walsh (2007) distinguish seven types of university-industry links: (i) research partnerships, (ii) research services, (iii) academic entrepreneurship, (iv) human resource transfer, (v) informal interaction, (vi) commercialization of property rights and (vii) scientific publications. The present section focuses on research partnerships, research services, academic entrepreneurship and commercialization of property rights. We covered the transfer of human resources and the importance of scientific publications for industrial innovation in Section 4.

5.1 Research partnerships

Perkmann and Walsh (2007) follow Hall, Link, and Scott (2003) and define them as formal collaborative arrangements among organizations with the objective to cooperate on research and development activities. In the context of university-industry collaborations, most of these research partnerships receive public support. Section 3.2 has already dealt with those types of university-industry collaborations. In this section, we focus on aspects which we left undiscussed.

In their seminal paper on industry-science links based on Belgian CIS data, Veugelers and Cassiman (2005) report that large firms and firms in the chemical and pharmaceutical industry are more likely to engage in industry-science partnerships. They additionally find that collaboration between science and industry are undertaken whenever risk does not constitute an important obstacle and when the partners have the objective to share costs. Consistent with the emerging open science paradigm, the authors do not find empirical evidence for the capacity to appropriate the returns from conducting joint innovation to be important for university-industry collaboration.

Empirical evidence for the impact of university-industry collaboration on industrial innovation is scarce. Beck and Lopes Bento (2016) study use Swiss CIS data and find that large firms can more effectively appropriate collaboration innovation activities with science partners relative to SMEs. Smaller firms, however, find it harder to reap the returns of collaboration with science partners. This is particularly so if they do not collaborate with other types of partners. Beck and Lopes-Bento (2016) argue that SMEs can improve incremental innovation performance by narrowing their

configuration boundaries with respect to science partners, suggesting that the requirement of collaborating with a science partner that applies to many subsidy schemes in order to qualify for public innovation support should be reconsidered for SMEs.

These results are in line with earlier research by Robin and Schubert (2013) who evaluate the impact of cooperation with public research institutes on firms' product and process innovation using French and German CIS data from 2004 and 2008. Similar to the recommendations of Beck and Lopes-Bento (2016), they argue that "public-private collaborations in research should not be encouraged at all costs, since they may not sustain all forms of innovation (p.149)." Robin and Schubert (2013) find that while cooperating with public research increases product innovation, it does not have any effect on process innovation.

Arvanitis and Woerter (2015) evaluate factors influencing the exploration and exploitation of knowledge in collaboration with universities. They further evaluate the impact of knowledge exploration versus knowledge exploitation on innovation performance using Swiss CIS data. They find a positive effect on innovation performance for exploitation-oriented firms but no effect for those firms engaged in both exploitive and explorative activities.

In another study that uses Swiss firm-level data, Arvanitis, Sydow, and Woerter (2008a) investigate whether alternative forms of university-industry knowledge transfer have alternative effects on firm-level innovation performance. They find that research partnerships with science seem to improve radical as well as incremental innovation performance, whereas the strength of the effects are of similar magnitude. The general positive effect of research partnerships on innovation performance and labour productivity is supported by a related study by Arvanitis, Sydow, and Woerter (2008b).

5.2 Research services: consulting and technology transfer offices

Perkmann and Walsh (2007) define "academic consulting" as paid services performed by university researchers for external clients. These arrangements are hence more asymmetric in nature compared to research partnerships, as the projects are defined more unilaterally by the client. Empirical evidence on the impact of academic consulting on corporate innovation is scarce. It does, however, constitute an important means

through which university research outcomes is transferred to industry as shown by Cohen, Nelson, and Walsh (2002) using the Yale survey data. One of the very few empirical analyses on academic consulting is performed by Arvanitis, Sydow and Woerter (2008a), who do not find that academic consulting positively impacts firms' innovation performance. Taking a broader perspective, D'Este and Perkmann (2011) analyse how universities' research quality affects university-industry relationships using a data set from the UK. They find that the relationship between faculty quality and industry involvement is different across academic disciplines and that it depends on complementarities between industrial and academic research. It also depends on resource requirements. Their results suggest that in technology-oriented disciplines, the research quality of a university department is positively related to industry involvement. With respect to social sciences, they find some support for a negative relationship between faculty quality and industry involvement. From a policy perspective, their findings suggest that discipline-specific approaches are needed to promote university–industry interaction.

University-based technology transfer offices are mediators between science and industry (Debackere and Veugelers, 2005). Comparing the technology transfer mechanisms from a sample of European research universities with the practices at KU Leuven, a leading Belgian research institution, they derive a framework that describes “the context, the structure and the processes that universities can use to become active players in the scientific knowledge market, managing and applying academic science, technology and innovation from an exploitation perspective.” This framework consists of decentralized organizational approaches and incentives for the stimulation of an active involvement of research groups in the exploitation of their research findings in combination with specialized central services offering intellectual property management and spin-off support (Debackere and Veugelers, 2005). Their findings suggest that critical success factors to stimulate an “effective“ commercialization of the academic science base are (i) an appropriate balance between centralization and decentralization within academia, (ii) the design of appropriate incentive structures for academic research groups and (iii) the implementation of appropriate decision and monitoring processes within the TTO.

5.3 Academic entrepreneurship and creation of new firms

Perkmann, King, and Pavelin (2011) define academic entrepreneurship as the development and commercial exploitation of technologies pursued by academic inventors through a company they (partly) own.

Vincett (2010) surveys Canadian firms four decades and analyses the economic impact of academic spin-offs from more applied sciences (non-medical natural sciences and engineering) and more basic sciences (physics). He finds that the effects of academic spin-offs exceed the effects of government funding by a substantial margin. Comparing the different disciplines, he finds that Physics performs actually between 30 percent and 60 percent better than more applied fields. He further shows that spin-off provide substantial incremental contributions to national GDP, and that governments' additional tax income gained by the spin-offs is higher than what is spent on the funding of the spin-off. Some support for the positive economic impact of entrepreneurial university activities, specifically from spin-offs, is provided by the exploratory study of Guerrero, Cunningham, and Urbano (2015) using UK data for 147 universities from 2005-2007.

It is well documented that there is a strong relationship between the regional agglomeration of university spin-offs and top US research universities like Stanford and MIT (Saxenian 1994). Salter and Martin (2001) point out, however, that the link between public research institutions and the number of *successful* spin-offs is less clear. This is a conclusion shared by Bania, Eberts, and Fogarty (1993), who study startup activities in six US manufacturing sectors at the regional level and link them to the presence of research universities. Quintas, Wield, and Massey (1992) study US science parks to conclude that science park startups are characterized by comparatively low growth rates. Storey and Tether (1998) review European studies on university spin-offs and find that they have lower growth rates than traditional firms. This conclusion is shared by Zhang (2009) who uses US venture capital data to show that university spin-offs tend to survive longer but are not different from other startups with respect to the amount of venture capital raised, employment, profit or the likelihood of having a successful IPO.

Baptista and Mendonça (2010) use Portuguese register panel data and link the data to the regional supply of students and graduates as well as to their proximity to a regional university. They estimate count-data models for firm entry to show that proximity to universities has a positive effect on startup activity. Fritsch and Aamoucke (2013)

demonstrate that such links also exist in Germany. Using a comprehensive data set on startup activity to which they attach the number of local public research institutions, they stress the importance of localized knowledge for innovative startup activity and in particular the contribution of public research institutions for founding activities.

In an attempt to identify why universities differ with respect to the success of their spin-offs, Di Gregorio and Shane (2003) use data made available by the US Association of University Technology Managers (AUTM). Their count-data regressions single out two key drivers of university startup success: faculty research quality and equity investments provided by the university.

From a policy perspective, Fini, Grimaldi, Santoni, and Sobrero (2011) show that the marginal effect on universities' spin-off productivity depends on local and regional support mechanisms in Italy, including legislative support, regional social capital, regional financial development, the presence of regional business incubators and regional public R&D expenses as well as the level of regional innovation performance. They argue that the design of effective universities needs to take into account regional specificities. Colombo, Piva, and Rentocchini (2012) provide additional Italian evidence. They analyse the effects of business incubators on high-tech start-ups on a large sample of firms in Italy. Their findings show that incubated high-tech start-ups perform better than non-incubated control firms.

Nielsen (2015) uses Danish register data to investigate the performance and choice of industry of new ventures by academic entrepreneurs. He shows that technically trained academics perform better in high-profit as well as in uncertain industries, while non-technical academics only perform better in high-profit industries. The findings indicate that both types of academics have a higher likelihood to enter uncertain industries. The findings suggest that the absorptive capacity of technical academics deems them particularly relevant for the transfer of technological knowledge into new ventures in uncertain and unstable environments.

Many spin-offs commercialize university property rights, the transfer of university-generated IP to firms (Perkmann and Walsh, 2007). Roessner, Bond, Okubo, and Planting (2013) estimate the economic impact of licensed commercialized inventions originating in university research on the US economy. Their approach combines IP licensing data from US universities with national input-output model coefficients. Even

their most conservative model indicates that the economic impact on GDP, industry output and employment is economically very substantial.

5.4 Entrepreneurship and technology policy

Policy has promoted science, technology and innovation parks as important parts of its overall innovation policies. Earlier research has shown that being located in a park supports firms to engage in collaboration but does not necessarily lead to improved performance. These studies are, however, likely to suffer from severe self-selection bias. Vásquez-Urriago, Barge-Gil, Rico, and Paraskevopoulou (2014) account for selection bias and confirm that location in a science and technology park positively affects the likelihood to collaborate and increases the likelihood of intangible benefits of collaboration with the main innovation partner which might be due to a more diverse relationship network. The latter finding is supported by Beck and Schenker–Wicki (2014) for Swiss CIS data.

In a study on the performance of Spanish Science and Technology Parks (STP), Perkmann, King, and Pavelin (2014) estimate the average treatment effect for firms located in these STPs. Their analysis shows that location in a STP has a positive impact on the probability and amount of product innovations, even if it is accounted for the endogeneity of STP location choice. Díez-Vial and Fernández-Olmos (2015) analyse the relevance of Spanish STPs as locations fostering local knowledge sharing and stimulating innovation. Their Tobit models indicate that firms with previous experience in collaboration with universities and research institutions benefit most from being located in a STP. They argue that this might be because firms with experience are better able to integrate existing knowledge from the STP. Their findings also suggest that product innovation is more likely to occur if firms with internal R&D reciprocally share the knowledge.

Another focus of policy makers has been on the establishment and promotion of (regional) industrial clusters. The role of local or regional clusters to foster local competitiveness in the private sector is highly controversially discussed in academic research. The difference-in-difference estimation analysis by Falck, Heblich, and Kipar (2010) evaluates the effectiveness of a cluster-oriented policy initiated by the Federal state Bavaria in Germany in 1999. The main policy objective was to stimulate corporate innovation and regional competitiveness through collaboration among firms. According to the study, the policy succeeded in increasing the likelihood of firms to become

innovators in the target industry by 4.6 to 5.7 percentage points. At the same time, R&D expenditures in those industries decreased by 19.4 percentage points on average. Additionally, the policy supported firms to engage in collaboration with public research institutes, and the availability of suitable R&D labor increased.

Positive effects of cluster participation is also found by Maine, Shapiro, and Vining (2010), who investigate the relationship between clustering and growth performance of new technology firms in the US. Their analysis provides empirical evidence for distance from a cluster being negatively correlated with corporate growth. The results further indicate that the impact of being located in a cluster is greater for biotech firms. The authors argue that geographical proximity to a cluster within a diverse metropolitan area is related to higher growth performance only if firms are well integrated “broad, downstream supply chain effects”, for example in information and communication technology.

Japanese evidence is provided by Nishimura and Okamuro (2011) who show that participation in a cluster alone does not necessarily affect R&D productivity. They find that collaboration in R&D with a partner in the same cluster region leads to a decrease in the quantity and quality of patents. However, firms participating in a cluster have a larger number of patent applications when they collaborate with national universities located in the same cluster. The authors suggest that in order to create positive effects of a cluster initiative, it is important to establish a network of wide-range collaboration within and beyond the cluster.

5.5 Wrap-up

The existing literature has pointed out that knowledge and technology are important characteristics of innovation and constitute important drivers of economic growth. The policy instruments considered in this section all seek to mitigate market failures in R&D and innovation. It reaches six main policy conclusions: First, research partnerships have a positive effect on innovation. It does, however, exist a great deal of heterogeneity. Second, empirical evidence on academic consulting is missing. Third, many studies discuss how TTOs should ideally work, but there is very little robust evidence on the performance of TTOs. Fourth, there exist large amount of heterogeneity in studies that analyze TTO performance. A common finding is, however, that there are more academic spin-offs than “ordinary” start-ups but these do not necessarily perform better. Fifth, there is not much empirical evidence on the outcome

effects of intellectual property rights owned by universities. Sixth, the literature emphasizes that university R&D may play an important role as an “entrepreneurial mediator” in a region with high entrepreneurial activity.

*“There is nothing a government
hates more than being well-informed;
for it makes the process of arriving at
decisions much more complicated
and difficult.”*

– John Maynard Keynes. *The Times* (March 11, 1937)

6. Conclusions

6.1 Main findings

Even though the literature reviewed in this survey is generally based on weak empirical identification, there are some broad findings that have so far been produced. First, private R&D and R&D subsidies – be it in the form of tax deductions or direct subsidies – are positively correlated, and there is no evidence for crowding-out effects. Second, R&D cooperation increases private R&D. Third, there appear to exist complementarities between alternative sources of funding. Fourth, the mobility of R&D workers – and in particular the movement of university scientists to industry – is positively related to corporate innovation. Fifth, there are comparatively many university spin-offs, but these are no more successful than non-university spin-offs. Sixth, universities constitute important collaboration partners. Seventh, clusters enhance collaboration, patents and productivity.

A common problem in much of the literature reviewed in this survey is that it measures simple correlations. Few studies use quasi-experiments or sensible instrumental variables estimation. It hence appears difficult to arrive at sharp policy conclusions. By the same token, and given the vast amounts of money spent by governments on R&D all over the world, it seems advisable to allocate some of these funds to policy experiments as is common practice in labor economics. Better data simply leads to better informed and more comprehensive policy advice.

Another problem for economic policy is that little is known about the optimal design of policy measures, since most studies only analyze a single policy initiative. This

prevents an analysis of how different policy measure should optimally be combined and how large each component should be. Similarly, little is known about the long-run effects of government intervention.

With respect to labor mobility, the presumption that mobility of university scientists to industry enhances corporate innovation ignores that such moves entail a loss to academia that has not yet been quantified.

A final problem is the aggregation of the primarily micro-founded results. The analyses covered in this review are all partial and do not consider second-order effects like changes in the competitive environment due to innovation. It seems, however, to be premature to tackle the aggregation problem as long as the micro-foundations remain weak.

6.2 Limitations and future research

Our review covers the most important channels through which public policy affect corporate innovation performance. However, there remain a few channels that we do not review. First, we are not concerned with innovation that is not directly related to R&D efforts, such as organizational and marketing innovations. Second, we do not deal with rent spillovers which occur when firms purchase products with embodied R&D and where the product price may not fully cover the value of the product. This channel seems to be important in the long-run when new technologies are adopted. Comin (2000) as well as Comin and Hobijn (2007) make the point that most of the societal returns to R&D comes through technology adoption.

A limitation of the current literature unfolds in the problem that although empirical studies often come with a high standard of internal validity, they are limited in their external validity. This lack of external validity together with the inherent difficulties to aggregate micro empirical evidence to a macro level hampers the provision of meaningful policy guidance. In order to strengthen the general relevance for society, future avenues in economic research should deal with the problem of how to transfer knowledge derived from empirical studies into relevant and meaningful policy guidance.

Appendix

Search results

Research question	# of hits	#screening on title	#screening on criteria
(a)	1115	460	48
(b)	396	48	36
(1)	229	17	54
(2)	139	31	27
(3)	57	21	24
(4)	37	15	14
(5)	303	84	46
TOTAL AMOUNT	2276	592	204

Note: (a) (b).

References

- Abramovsky, L. and Simpson, H. 2011. Geographic proximity and firm–university innovation linkages: evidence from Great Britain. *Journal of economic geography*, 11(6): 949-977.
- Adams, J. D. 1990. Fundamental stocks of knowledge and productivity growth. *Journal of Political Economy*, 98(4): 673-702.
- Aerts, K. and Schmidt, T. 2008. Two for the price of one? *Research Policy*, 37(5): 806-822.
- Arora, A. and Cohen, W. M. 2015. Public support for technical advance: the role of firm size. *Industrial and Corporate Change*, 24(4): 791-802.
- Arrow, K. J. 1962. Economic welfare and the allocation of resources for invention. In R. Nelson (Ed.), *The Rate and Direction of Inventive Activity*: 609-626: Princeton Univ. Press, Princeton, NJ.
- Arundel, A., Van de Paal, G., and Soete, L. 1995. Innovation strategies of Europe's largest firms: Results of the PACE survey for information sources, public research, protection of innovations and government programmes, *Final Report, MERIT, University of Limburg, Maastricht*.
- Arundel, A. and Geuna, A. 2004. Proximity and the use of public science by innovative European firms. *Economics of Innovation and new Technology*, 13(6): 559-580.
- Arvanitis, S., Sydow, N., and Woerter, M. 2008a. Do specific forms of university–industry knowledge transfer have different impacts on the performance of private enterprises? An empirical analysis based on Swiss firm data. *The Journal of Technology Transfer*, 33(5): 504-533.
- Arvanitis, S., Sydow, N., and Woerter, M. 2008b. Is there any impact of university–industry knowledge transfer on innovation and productivity? An empirical analysis based on Swiss firm data. *Review of Industrial Organization*, 32(2): 77-94.
- Arvanitis, S., Donze, L., and Sydow, N. 2010. Impact of Swiss technology policy on firm innovation performance: an evaluation based on a matching approach. *Science and Public Policy*, 37(1): 63-78.
- Arvanitis, S. 2013. Micro-econometric approaches to the evaluation of technology-oriented public programmes: a non-technical review of the state of the art. *Handbook on the Theory and Practice of Program Evaluation*: 56-88.
- Arvanitis, S. and Woerter, M. 2015. Exploration or exploitation of knowledge from universities: does it make a difference? *Economics of Innovation and New Technology*, 24(6): 596-623.
- Aschhoff, B. 2009. The effect of subsidies on R&D investment and success—Do subsidy history and size matter? *ZEW-Centre for European Economic Research Discussion Paper*(09-032).
- Bacchiocchi, E. and Montobbio, F. 2010. International Knowledge Diffusion and Home-bias Effect: Do USPTO and EPO Patent Citations Tell the Same Story? *The Scandinavian Journal of Economics*, 112(3): 441-470.
- Baghana, R. and Mohnen, P. 2009. Effectiveness of R&D tax incentives in small and large enterprises in Qu, bec. *Small Business Economics*, 33(1): 91-107.
- Bania, N., Eberts, R. W., and Fogarty, M. S. 1993. Universities and the startup of new companies: can we generalize from route 128 and Silicon valley? *The review of economics and statistics*: 761-766.
- Baptista, R. and Mendonça, J. 2010. Proximity to knowledge sources and the location of knowledge-based start-ups. *The Annals of Regional Science*, 45(1): 5-29.

- Barge-Gil, A. and Lopez, A. 2015. R versus D: estimating the differentiated effect of research and development on innovation results. *Industrial and Corporate Change*, 24(1): 93-129.
- Beck, M. and Schenker–Wicki, A. 2014. Cooperating with external partners: the importance of diversity for innovation performance. *European Journal of International Management*, 8(5): 548-569.
- Beck, M. and Lopes Bento, C. 2016. Innovation Outcomes and Partner-Type Selection in R&D Alliances: The Role of Simultaneous Diversification and Sequential Adaptation. **Available at SSRN 2823572**, UZH Business Working Paper Series.
- Beck, M., Lopes-Bento, C., and Schenker-Wicki, A. 2016. Radical or incremental: Where does R&D policy hit? *Research Policy*, 45(4): 869-883.
- Becker, B. 2015. Public R&D Policies and Private R&D Investment: A Survey of the Empirical Evidence. *Journal of Economic Surveys*, 29(5): 917-942.
- Beise, M. and Stahl, H. 1999. Public research and industrial innovations in Germany. *Research Policy*, 28(4): 397-422.
- Belenzon, S. and Schankerman, M. 2013. Spreading the Word: Geography, Policy, and Knowledge Spillovers. *Review of Economics and Statistics*, 95(3): 884-903.
- Berstein, J. I. and Mamuneas, T. P. 2005. Depreciation estimation, R&D capital stock, and North American manufacturing productivity growth. *Annales d'Économie et de Statistique*: 383-404.
- Bishop, K., D'Este, P., and Neely, A. 2011. Gaining from interactions with universities: Multiple methods for nurturing absorptive capacity. *Research Policy*, 40(1): 30-40.
- Bloch, C. and Graversen, E. K. 2008. Additionality of public R&D funding in business R&D. *Danish Centre for Studies in Research and Research Policy, University of Aarhus*.
- Bloom, N., Griffith, R. and van Reenen, J. (2002). Do R&D tax credits work? Evidence from a panel of countries 1979-1997. *Journal of Public Economics*, 85: 1-31.
- Branstetter, L. G. and Sakakibara, M. 2002. When Do Research Consortia Work Well and Why? Evidence from Japanese Panel Data. *The American Economic Review*, 92(1): 143-159.
- Busom, I. and Fernandez-Ribas, A. 2008. The impact of firm participation in R&D programmes on R&D partnerships. *Research Policy*, 37(2): 240-257.
- Caballero, R. J. and Jaffe, A. B. 1993. How high are the giants' shoulders: An empirical assessment of knowledge spillovers and creative destruction in a model of economic growth. *NBER macroeconomics annual*, 8: 15-74.
- Callon, M. 1994. Is science a public good? fifth mullins lecture, virginia polytechnic institute, 23 march 1993. *Science, Technology, and Human Values*, 19(4): 395-424.
- Cappelen, A., Raknerud, A., and Rybalka, M. 2012. The effects of R&D tax credits on patenting and innovations. *Research Policy*, 41(2): 334-345.
- Carboni, M. and Regazzi, D. 2011. Effect of the experimental technique onto R dependence of Delta Kth. *11th International Conference on the Mechanical Behavior of Materials (Icm11)*, 10(4): 419-439.
- Cassiman, B. and Veugelers, R. 2002. R&D cooperation and spillovers: Some empirical evidence from Belgium. *American Economic Review*, 92(4): 1169-1184.
- Cassiman, B., Veugelers, R., and Zuniga, P. 2008. In search of performance effects of (in)direct industry science links. *Industrial and Corporate Change*, 17(4): 611-646.
- Castellacci, F. and Lie, C. M. 2015. Do the effects of R&D tax credits vary across industries? A meta-regression analysis. *Research Policy*, 44(4): 819-832.

- Cerulli, G. and Poti, B. 2012. Evaluating the Robustness of the Effect of Public Subsidies on Firms' R&D: An Application to Italy. *Journal of Applied Economics*, 15(2): 287-320.
- Christensen, T., Kuhn, J., Schneider, C., and Sørensen, A. 2015. Science and Productivity—Evidence from a randomized natural experiment, *SIMPATIC final conference, Brussels, February*.
- Clausen, T. H. 2009. Do subsidies have positive impacts on R&D and innovation activities at the firm level? *Structural Change and Economic Dynamics*, 20(4): 239-253.
- Cockburn, I. M. and Henderson, R. M. 1998. Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *The Journal of Industrial Economics*, 46(2): 157-182.
- Cohen, W. M. and Levinthal, D. A. 1989. Innovation and Learning - the 2 Faces of R-and-D. *Economic Journal*, 99(397): 569-596.
- Cohen, W. M. and Levinthal, D. A. 1990. Absorptive-Capacity - a New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1): 128-152.
- Cohen, W. M., Nelson, R. R., and Walsh, J. P. 2002. Links and impacts: the influence of public research on industrial R&D. *Management science*, 48(1): 1-23.
- Colombo, M. G., Piva, E., and Rentocchini, F. 2012. The effects of incubation on academic and non-academic high-tech start-ups: evidence from Italy. *Economics of Innovation and New Technology*, 21(5-6): 505-527.
- Comin, D. 2000. An uncertainty-driven theory of the productivity slowdown: Manufacturing.
- Comin, D. and Hobijn, B. 2007. Implementing technology: National Bureau of Economic Research.
- Cowan, R. and Zinovyeva, N. 2013. University effects on regional innovation. *Research Policy*, 42(3): 788-800.
- Czarnitzki, D. and Hussinger, K. 2004. The link between R&D subsidies, R&D spending and technological performance: ZEW Discussion Papers.
- Czarnitzki, D. and Licht, G. 2006. Additionality of public R&D grants in a transition economy. *Economics of Transition*, 14(1): 101-131.
- Czarnitzki, D., Kraft, K., and Thorwarth, S. 2009. The knowledge production of 'R' and 'D'. *Economics Letters*, 105(1): 141-143.
- Czarnitzki, D., Hanel, P., and Rosa, J. M. 2011. Evaluating the impact of R&D tax credits on innovation: A microeconomic study on Canadian firms. *Research Policy*, 40(2): 217-229.
- Czarnitzki, D., Hussinger, K., and Schneider, C. 2011. Commercializing academic research: the quality of faculty patenting. *Industrial and Corporate Change*, 20(5): 1403-1437.
- Czarnitzki, D. and Lopes-Bento, C. 2012. Evaluation of public R&D policies: a cross-country comparison. *World Review of Science, Technology and Sustainable Development*, 9(2-4): 254-282.
- Czarnitzki, D. and Thorwarth, S. 2012. Productivity effects of basic research in low-tech and high-tech industries. *Research Policy*, 41(9): 1555-1564.
- Czarnitzki, D. and Lopes-Bento, C. 2014. Innovation subsidies: Does the funding source matter for innovation intensity and performance? Empirical evidence from Germany. *Industry and Innovation*, 21(5): 380-409.
- Czarnitzki, D. and Delanote, J. 2015. R&D policies for young SMEs: input and output effects. *Small Business Economics*, 45(3): 465-485.
- Czarnitzki, D., Huergo, E., Köhler, M., Mohnen, P., Pacher, T., T., , and Toivanen, O. 2015. Welfare effects of European R&D support policies. , vol. working paper no. 34.: SIMPATIC.

- D'Aspremont, C. and Jacquemin, A. 1988. Cooperative and Noncooperative R&D in Duopoly with Spillovers. *American Economic Review*, 78(5): 1133-1137.
- D'este, P. and Perkmann, M. 2011. Why do academics engage with industry? The entrepreneurial university and individual motivations. *The Journal of Technology Transfer*, 36(3): 316-339.
- Dasgupta, P. and David, P. A. 1994. Toward a New Economics of Science. *Research Policy*, 23(5): 487-521.
- David, P. A., Hall, B. H., and Toole, A. A. 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research Policy*, 29(4-5): 497-529.
- Debackere, K. and Veugelers, R. 2005. The role of academic technology transfer organizations in improving industry science links. *Research policy*, 34(3): 321-342.
- DeBondt, R. 1997. Spillovers and innovative activities. *International Journal of Industrial Organization*, 15(1): 1-28.
- Di Gregorio, D. and Shane, S. 2003. Why do some universities generate more start-ups than others? *Research policy*, 32(2): 209-227.
- Díez-Vial, I. and Fernández-Olmos, M. 2015. Knowledge spillovers in science and technology parks: how can firms benefit most? *The Journal of Technology Transfer*, 40(1): 70-84.
- Dimos, C. and Pugh, G. 2016. The effectiveness of R&D subsidies: A meta-regression analysis of the evaluation literature. *Research Policy*, 45(4): 797-815.
- Dorfman, N. S. 1983. Route-128 - the Development of a Regional High Technology Economy. *Research Policy*, 12(6): 299-316.
- Duguet, E. 2004. Are R&D subsidies a substitute or a complement to privately funded R&D? Evidence from France using propensity score methods for non-experimental data. *Revue d'économie politique*, 114(2): 245-274.
- Ejsing, A.-K., Kaiser, U., Kongsted, H. C., and Laursen, K. 2013. The Role of University Scientist Mobility for Industrial Innovation. *University of Zurich, Institute of Business Administration, UZH Business Working Paper*(332).
- Elschner, C., Ernst, C., Licht, G., and Spengel, C. 2011. What the design of an R&D tax incentive tells about its effectiveness: a simulation of R&D tax incentives in the European Union. *Journal of Technology Transfer*, 36(3): 233-256.
- Fahrenkrog, G. 2002. *RTD evaluation toolbox: assessing the socio-economic impact of RTD-policies*: European Commission, Joint Research Centre.
- Falck, O., Heblich, S., and Kipar, S. 2010. Industrial innovation: Direct evidence from a cluster-oriented policy. *Regional Science and Urban Economics*, 40(6): 574-582.
- Falk, M. 2006. What drives business Research and Development (R&D) intensity across Organisation for Economic Co-operation and Development (OECD) countries? *Applied Economics*, 38(5): 533-547.
- Faulkner, W. and Senker, J. 1994. Making sense of diversity: public-private sector research linkage in three technologies. *Research Policy*, 23(6): 673-695.
- Faulkner, W., Senker, J., and Velho, L. 1995. *Knowledge frontiers*: Clarendon Press.
- Fini, R., Grimaldi, R., Santoni, S., and Sobrero, M. 2011. Complements or substitutes? The role of universities and local context in supporting the creation of academic spin-offs. *Research Policy*, 40(8): 1113-1127.
- Foray, D. and Lissoni, F. 2010. University research and public-private interaction. *Handbook of the Economics of Innovation*, 1: 275-314.
- Fosse, H. B., Jacobsen, J., and Jacobsen, R. H. 2014. The Short-run Impact on Total Factor Productivity Growth: Of the Danish Innovation and Research Support System.

- Fritsch, M. and Aamoucke, R. 2013. Regional public research, higher education, and innovative start-ups: An empirical investigation. *Small Business Economics*, 41(4): 865-885.
- Frontier Economics. 2014. Rates of return to investment in science and innovation. **A report prepared for the UK Department for Business, Innovation and Skills (BIS).**
- Gibbons, M. and Johnston, R. 1974. The roles of science in technological innovation. *Research Policy*, 3(3): 220-242.
- Gittelman, M. and Kogut, B. 2003. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. *Management Science*, 49(4): 366-382.
- González, X. and Pazó, C. 2008. Do public subsidies stimulate private R&D spending? *Research Policy*, 37(3): 371-389.
- Görg, H. and Strobl, E. 2007. The effect of R&D subsidies on private R&D. *Economica*, 74(294): 215-234.
- Griliches, Z. 1979. Issues in Assessing the Contribution of Research and Development to Productivity Growth. *Bell Journal of Economics*, 10(1): 92-116.
- Griliches, Z., Hall, B. H., and Pakes, A. 1991. R&D, patents, and market value revisited: Is there a second (technological opportunity) factor? *Economics of Innovation and new technology*, 1(3): 183-201.
- Guellec, D. and Van Pottelsberghe De La Potterie, B. 2003. The impact of public R&D expenditure on business R&D*. *Economics of innovation and new technology*, 12(3): 225-243.
- Guerrero, M., Cunningham, J. A., and Urbano, D. 2015. Economic impact of entrepreneurial universities' activities: An exploratory study of the United Kingdom. *Research Policy*, 44(3): 748-764.
- Hall, B. and Van Reenen, J. 2000. How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy*, 29(4-5): 449-469.
- Hall, B. H., Link, A. N., and Scott, J. T. 2003. Universities as research partners. *Review of Economics and Statistics*, 85(2): 485-491.
- Hall, B. H. 2004. University-industry research partnerships in the United States: European University Institute Badia Fiesolana,, San Domenico, Italy.
- Hall, B. H., Lotti, F., and Mairesse, J. 2009. Innovation and productivity in SMEs: empirical evidence for Italy. *Small Business Economics*, 33(1): 13-33.
- Harris, R., Li, Q. C., and Trainor, M. 2009. Is a higher rate of R&D tax credit a panacea for low levels of R&D in disadvantaged regions? *Research Policy*, 38(1): 192-205.
- Henderson, R., Jaffe, A. B., and Trajtenberg, M. 1998. Universities as a source of commercial technology: A detailed analysis of university patenting, 1965-1988. *Review of Economics and Statistics*, 80(1): 119-127.
- Hottenrott, H. and Lopes-Bento, C. 2014. (International) R&D collaboration and SMEs: The effectiveness of targeted public R&D support schemes. *Research Policy*, 43(6): 1055-1066.
- Hottenrott, H., Lopes Bento, C., and Veugelers, R. 2015. Direct and cross-scheme effects in a research and development subsidy program. *ZEW-Centre for European Economic Research Discussion Paper*(14-107).
- Howells, J., Ramlogan, R., and Cheng, S. L. 2012. Innovation and university collaboration: paradox and complexity within the knowledge economy. *Cambridge Journal of Economics*, 36(3): 703-721.
- Hussinger, K. 2008. R&D and Subsidies at the Firm Level: An Application of Parametric and Semiparametric Two-Step Selection Models. *Journal of Applied Econometrics*, 23(6): 729-747.

- Jaffe, A. B. 1988. Demand and Supply Influences in R-and-D Intensity and Productivity Growth. *Review of Economics and Statistics*, 70(3): 431-437.
- Jaffe, A. B. 1989. Real Effects of Academic Research. *American Economic Review*, 79(5): 957-970.
- Jaffe, A. B. and Trajtenberg, M. 2002. *Patents, citations, and innovations: A window on the knowledge economy*. MIT press.
- Jaumotte, F. and Pain, N. 2005. An overview of public policies to support innovation.
- Jones, C. I. and Williams, J. C. 1998. Measuring the social return to R and D. *Quarterly Journal of Economics*: 1119-1135.
- Junge, M., Severgnini, B., and Sørensen, A. 2016. Product-Marketing Innovation, Skills, and Firm Productivity Growth. *Review of Income and Wealth*, 62(4): 724-757.
- Kaiser, U. 2002. An empirical test of models explaining research expenditures and research cooperation: evidence for the German service sector. *International Journal of Industrial Organization*, 20(6): 747-774.
- Kaiser, U. 2006. Private R&D and Public R&D subsidies: Microeconomic Evidence for Denmark. *Nationaløkonomisk Tidsskrift*, 144: 1-17.
- Kaiser, U. and Kuhn, J. M. 2012. Long-run effects of public-private research joint ventures: The case of the Danish Innovation Consortia support scheme. *Research Policy*, 41(5): 913-927.
- Kaiser, U., Kongsted, H. C., and Rønde, T. 2015. Does the mobility of R&D labor increase innovation? *Journal of Economic Behavior and Organization*, 110: 91-105.
- Kamien, M. I., Muller, E., and Zang, I. 1992. Research Joint Ventures and Research-and-Development Cartels. *American Economic Review*, 82(5): 1293-1306.
- Katz, M. L. 1986. An Analysis of Cooperative Research-and-Development. *Rand Journal of Economics*, 17(4): 527-543.
- Klette, T. J., Moen, J., and Griliches, Z. 2000. Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies. *Research Policy*, 29(4-5): 471-495.
- Klette, T. J. and Møen, J. 2012. R&D investment responses to R&D subsidies: A theoretical analysis and a microeconomic study. *World Review of Science, Technology and Sustainable Development*, 9(2-4): 169-203.
- Klevorick, A. K., Levin, R. C., Nelson, R. R., and Winter, S. G. 1995. On the Sources and Significance of Interindustry Differences in Technological Opportunities. *Research Policy*, 24(2): 185-205.
- Lach, S. 2002. Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. *Journal of Industrial Economics*, 50(4): 369-390.
- Laursen, K., Reichstein, T., and Salter, A. 2011. Exploring the effect of geographical proximity and university quality on university–industry collaboration in the United Kingdom. *Regional studies*, 45(4): 507-523.
- Leten, B., Landoni, P., and Van Looy, B. 2014. Science or graduates: How do firms benefit from the proximity of universities? *Research Policy*, 43(8): 1398-1412.
- Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R., and Griliches, Z. 1987. Appropriating the returns from industrial research and development. *Brookings papers on economic activity*, 1987(3): 783-831.
- List, J. A. and Rasul, I. 2011. Field Experiments in Labor Economics. *Handbook of Labor Economics, Vol 4a*, 4: 103-228.
- Lokshin, B. and Mohnen, P. 2012. How effective are level-based R&D tax credits? Evidence from the Netherlands. *Applied Economics*, 44(12): 1527-1538.
- Maietta, O. W. 2015. Determinants of university-firm R&D collaboration and its impact on innovation: A perspective from a low-tech industry. *Research Policy*, 44(7): 1341-1359.

- Maine, E. M., Shapiro, D. M., and Vining, A. R. 2010. The role of clustering in the growth of new technology-based firms. *Small Business Economics*, 34(2): 127-146.
- Mansfield, E. 1991. Social returns from R&D: findings, methods and limitations. *Research Technology Management*, 34(6): 24.
- Mansfield, E. 1995. Academic Research Underlying Industrial Innovations - Sources, Characteristics and Financing. *Review of Economics and Statistics*, 77(1): 55-62.
- Martin, B. and Irvine, J. 1981. Spin-off from basic science: the case of radioastronomy. *Physics in Technology*, 12(5): 204.
- Martin, B. R., Hicks, D., and Salter, A. 1996. *The relationship between publicly funded basic research and economic performance: A SPRU review*. Science Policy Research Unit, University of Sussex.
- Martin, S. and Scott, J. T. 2000. The nature of innovation market failure and the design of public support for private innovation. *Research Policy*, 29(4-5): 437-447.
- McMillan, G. S., Narin, F., and Deeds, D. L. 2000. An analysis of the critical role of public science in innovation: the case of biotechnology. *Research Policy*, 29(1): 1-8.
- Meyer, M. 2000. Does science push technology? Patents citing scientific literature. *Research policy*, 29(3): 409-434.
- Meyer-Krahmer, F. and Schmoch, U.. 1998. Science-based technologies: university-industry interactions in four fields. *Research Policy*, 27(8): 835-851.
- Mowery, D. 1995. The practice of technology policy. *Handbook of the economics of innovation and technological change*: 513-557.
- Mowery, D. C., Nelson, R. R., Sampat, B. N., and Ziedonis, A. A. 2001. The growth of patenting and licensing by US universities: an assessment of the effects of the Bayh-Dole act of 1980. *Research Policy*, 30(1): 99-119.
- Mowery, D. C. and Sampat, B. N. 2004. The Bayh-Dole Act of 1980 and university-industry technology transfer: a model for other OECD governments? *The Journal of Technology Transfer*, 30(1-2): 115-127.
- Mowery, D. C. and Ziedonis, A. A. 2015. Markets versus spillovers in outflows of university research. *Research Policy*, 44(1): 50-66.
- Mulkay, B. and Mairesse, J. 2013. The R&D tax credit in France: assessment and ex ante evaluation of the 2008 reform. *Oxford Economic Papers-New Series*, 65(3): 746-766.
- Muscio, A., Quaglione, D., and Vallanti, G. 2013. Does government funding complement or substitute private research funding to universities? *Research Policy*, 42(1): 63-75.
- Narin, F. and Olivastro, D. 1992. Status-Report - Linkage between Technology and Science. *Research Policy*, 21(3): 237-249.
- Narin, F., Hamilton, K. S., and Olivastro, D. 1997. The increasing linkage between US technology and public science. *Research policy*, 26(3): 317-330.
- Nelson, R. R. 1959. The Simple Economics of Basic Scientific-Research. *Journal of Political Economy*, 67(3): 297-306.
- Nelson, R. R. 1986. Institutions Supporting Technical Advance in Industry. *American Economic Review*, 76(2): 186-189.
- Nelson, R. R. 2006. Reflections on "The simple economics of basic scientific research": Looking back and looking forward. *Industrial and Corporate Change*, 15(6): 903-917.
- Nielsen, K. 2015. Human capital and new venture performance: the industry choice and performance of academic entrepreneurs. *The Journal of Technology Transfer*, 40(3): 453-474.

- Nightingale, P. 1997. **Knowledge and technical change: computer simulations and the changing innovation process**. University of Sussex.
- Nishimura, J. and Okamuro, H. 2011. R&D productivity and the organization of cluster policy: An empirical evaluation of the Industrial Cluster Project in Japan. **The Journal of Technology Transfer**, 36(2): 117-144.
- Østergaard, C. R. 2007. Knowledge flows through social networks in a cluster: interfirm versus university-industry Contacts. **Structural Change and Economic Dynamics**.
- Pavitt, K. 1991. What makes basic research economically useful? **Research Policy**, 20(2): 109-119.
- Pavitt, K. 1998. The social shaping of the national science base. **Research Policy**, 27(8): 793-805.
- Perkmann, M. and Walsh, K. 2007. University–industry relationships and open innovation: Towards a research agenda. **International Journal of Management Reviews**, 9(4): 259-280.
- Perkmann, M., King, Z. , and Pavelin, S. 2011. Engaging excellence? Effects of faculty quality on university engagement with industry. **Research Policy**, 40: 539-552.
- Quaglione, D., Muscio, A., and Vallanti, G. 2015. The two sides of academic research: do basic and applied activities complement each other? **Economics of Innovation and New Technology**, 24(7): 660-681.
- Quintas, P., Wield, D., and Massey, D. 1992. Academic-industry links and innovation: questioning the science park model. **Technovation**, 12(3): 161-175.
- Rappa, M. A. and Debackere, K. 1992. Technological communities and the diffusion of knowledge. **R&D Management**, 22(3): 209-220.
- Robin, S. and Schubert, T. 2013. Cooperation with public research institutions and success in innovation: Evidence from France and Germany. **Research Policy**, 42(1): 149-166.
- Roessner, D., Bond, J., Okubo, S., and Planting, M. 2013. The economic impact of licensed commercialized inventions originating in university research. **Research Policy**, 42(1): 23-34.
- Romer, P. M. 1990. Endogenous Technological-Change. **Journal of Political Economy**, 98(5): S71-S102.
- Rosenberg, N. 1990. Why Do Firms Do Basic Research with Their Own Money. **Research Policy**, 19(2): 165-174.
- Rosenberg, N. 1992. Scientific Instrumentation and University-Research. **Research Policy**, 21(4): 381-390.
- Rosenberg, N. and Nelson, R. R. 1994. American Universities and Technical Advance in Industry. **Research Policy**, 23(3): 323-348.
- Rothaermel, F. T. and Hess, A. M. 2007. Building dynamic capabilities: Innovation driven by individual-, firm-, and network-level effects. **Organization science**, 18(6): 898-921.
- Rothaermel, F. T. and Ku, D. N. 2008. Intercluster innovation differentials: the role of research universities. **IEEE Transactions on Engineering Management**, 55(1): 9-22.
- Sakakibara, M. 2001. The diversity of R&D consortia and firm behavior: Evidence from Japanese data. **Journal of Industrial Economics**, 49(2): 181-196.
- Salter, A. J. and Martin, B. R. 2001. The economic benefits of publicly funded basic research: a critical review. **Research Policy**, 30(3): 509-532.
- Santamaría, L., Barge-Gil, A., and Modrego, A. 2010. Public selection and financing of R&D cooperative projects: Credit versus subsidy funding. **Research Policy**, 39(4): 549-563.
- Saxenian, A. 1994. Regional networks: industrial adaptation in Silicon Valley and route 128.

- Schumpeter, J. 1934. *Capitalism, socialism, and democracy*: New York: Harper and Row.
- Senker, J. 1995. Tacit knowledge and models of innovation. *Industrial and corporate change*, 4(2): 425-447.
- Shane, S. A. 2004. *Academic entrepreneurship: University spin-offs and wealth creation*: Edward Elgar Publishing.
- Siegel, D. S., Veugelers, R., and Wright, M. 2007. Technology transfer offices and commercialization of university intellectual property: performance and policy implications. *Oxford review of economic policy*, 23(4): 640-660.
- Steinmueller, W. E. 1994. Basic research and industrial innovation. *The Handbook of Industrial Innovation, Edward Elgar, Aldershot*: 54-66.
- Storey, D. J. and Tether, B. S. 1998. New technology-based firms in the European Union: an introduction. *Research policy*, 26(9): 933-946.
- Thursby, J. G., Jensen, R., and Thursby, M. C. 2001. Objectives, characteristics and outcomes of university licensing: A survey of major US universities. *The Journal of Technology transfer*, 26(1-2): 59-72.
- Toole, A. A. 2007. Does public scientific research complement private investment in research and development in the pharmaceutical industry? *The Journal of Law and Economics*, 50(1): 81-104.
- Toole, A. A. 2012. The impact of public basic research on industrial innovation: Evidence from the pharmaceutical industry. *Research Policy*, 41(1): 1-12.
- Valero, A. and Van Reenen, J. 2016. The economic impact of universities: Evidence from across the globe: National Bureau of Economic Research.
- Vásquez-Urriago, Á. R., Barge-Gil, A., Rico, A. M., and Paraskevopoulou, E. 2014. The impact of science and technology parks on firms' product innovation: empirical evidence from Spain. *Journal of Evolutionary Economics*, 24(4): 835-873.
- Veugelers, R., Calis, E. A., Penning, C., Verhagen, A., Bernsen, R., Bouquet, J., Benninga, M. A., Merkus, P. J., Arets, H. G., Tibboel, D., and Evenhuis, H. M. 2005. A population-based nested case control study on recurrent pneumonias in children with severe generalized cerebral palsy: ethical considerations of the design and representativeness of the study sample. *BMC Pediatr*, 5(5,Äi6): 25.
- Veugelers, R. and Cassiman, B. 2005. R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing. *International Journal of Industrial Organization*, 23(5): 355-379.
- Vincett, P. S. 2010. The economic impacts of academic spin-off companies, and their implications for public policy. *Research Policy*, 39(6): 736-747.
- Warda, J. 2009. An update of R&D tax treatment in OECD countries and selected emerging economies, 2008-2009: mimeo.
- Yang, C. H., Huang, C. H., and Hou, T. C. T. 2012. Tax incentives and R&D activity: Firm-level evidence from Taiwan. *Research Policy*, 41(9): 1578-1588.
- Zahra, S. A. and George, G. 2002. Absorptive capacity: A review, reconceptualization, and extension. *Academy of Management Review*, 27(2): 185-203.
- Zhang, J. 2009. The performance of university spin-offs: an exploratory analysis using venture capital data. *The Journal of Technology Transfer*, 34(3): 255-285.
- Zucker, L. G., Darby, M. R., and Brewer, M. B. 1994. Intellectual capital and the birth of US biotechnology enterprises: National Bureau of Economic Research.
- Zucker, L. G., Darby, M. R., and Torero, M. 2002. Labor mobility from academe to commerce. *Journal of Labor Economics*, 20(3): 629-660.
- Zúñiga-Vicente, J. Á., Alonso-Borrego, C., Forcadell, F. J., and Galán, J. I. 2014. Assessing the effect of public subsidies on firm R&D investment: a survey. *Journal of Economic Surveys*, 28(1): 36-67.